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AN ANALYSIS OF TIROS II RADIATION DATA RECORDED OVER NEW ZEALAND AT NIGHT

by Lewis J. Allison

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SUMMARY

Infrared radiation measurements in the 8-12μ, 8-30μ, and 6.0-6.5μ wavelength regions taken by Tiros II on its initial orbit over New Zealand are examined in detail. A subjective analysis of the synoptic situation confirmed the two broad-scale frontal systems clearly outlined by the Tiros II radiation data recorded over the Tasman Sea at night. The equivalent blackbody temperatures measured in the 8-12μ region were found to be 6° to 12°K colder than the sea water temperatures in warm radiation source areas. In the 6.0-6.5μ region the equivalent blackbody temperatures, when converted to "effective radiation height," averaged 8705 feet below the tropopause at five upper air stations.

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(Manuscript Received June 26, 1963)

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Lewis J. Allison
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INTRODUCTION

The Tiros II meteorological satellite (1960 pi I) was launched from Cape Canaveral, Florida, on November 23, 1960. It was spin-stabilized and space-oriented in a nearly circular orbit (apogee 454.4 statute miles, perigee 385.6 statute miles) with a period of 98.3 minutes. Tiros II was the first satellite to be equipped with a five-channel scanning radiometer to measure reflected solar radiation and infrared emission from the earth and its atmosphere, in addition to the two-television-camera system.

The radiation data selected for this analysis were obtained during Orbit Zero as the satellite initially viewed the New Zealand area. This study is a preliminary attempt to analyze the radiation data to delineate nighttime cloud cover over a remote oceanic area where meteorological information is at a minimum.

A brief description of the scanning radiometer and its regions of spectral sensitivity precedes the subjective analysis of the storm area. A comparison of frontal clouds with satellite radiation patterns and a preliminary tropopause height relationship with Channel 1 radiation data are presented.

THE SCANNING RADIOMETER

The five-channel scanning radiometer (Figure 1) measures the terrestrial and reflected solar radiation in selected regions of the infrared spectrum.

The five spectral regions and their characteristic functions[1] are:

Channel 1: 6.0-6.5μ - water vapor absorption band

Channel 2: 8-12μ - atmospheric window

Channel 3: 0.2-6μ - reflected solar radiation band

Channel 4: 8-30μ - thermal radiation from the earth and atmosphere

Channel 5: 0.55-0.75μ - visible reference and daytime cloud cover

The approximate transmission characteristics of the three long-wave channels (1, 2, and 4) are shown in Figure 2.

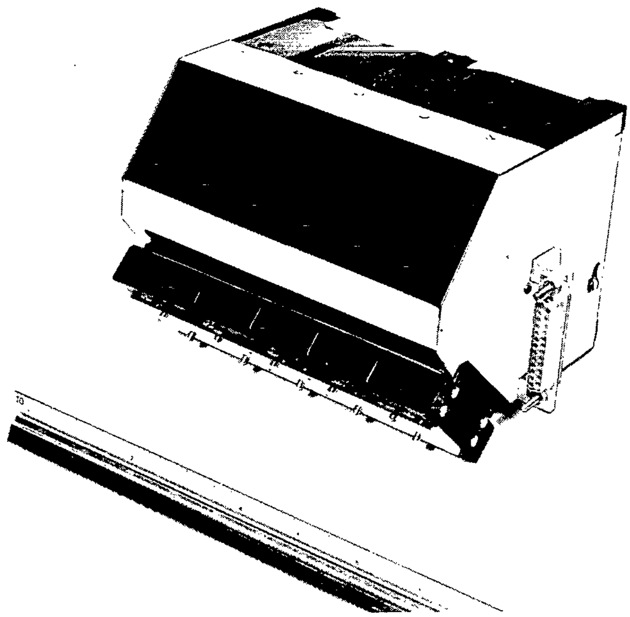

Figure 1—External View of the 5-Channel Scanning Radiometer Showing the View Aperatures in one direction.

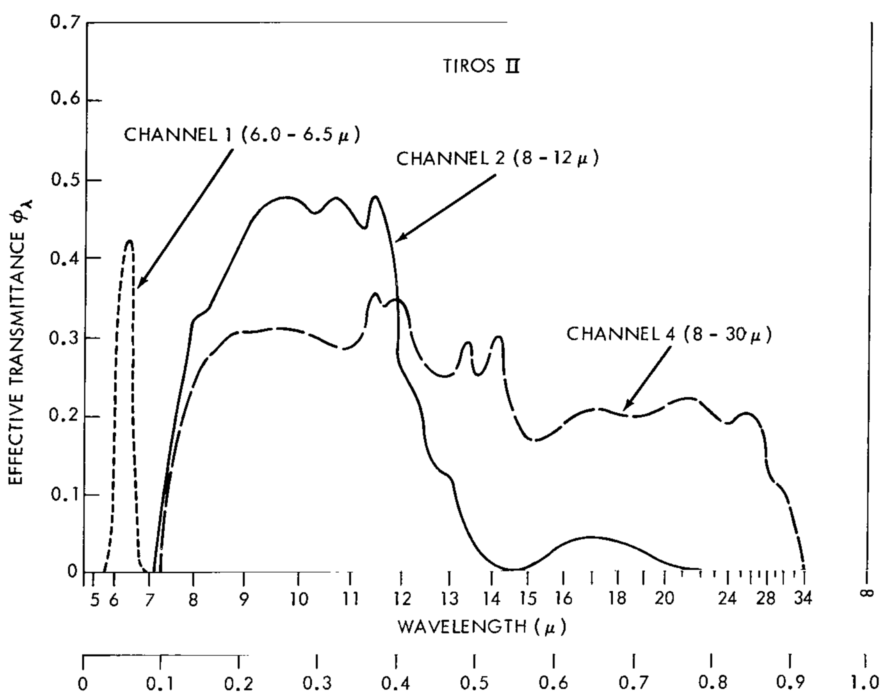

Figure 2—Spectral response characteristics of Channels 1, 2, and 4 of the 5-channel scanning radiometer.

Channel 2 primarily measures the radiation ($8-12\mu$) from the earth's surface if there are no clouds, or from the tops of clouds if they exist. The relationship between the cloud layers and the emitted infrared radiation has been expressed[2] as follows: "An overcast of dense middle and high clouds whose tops are cold, emits relatively little energy. By contrast, nearby areas of lower clouds or broken clouds or cloudless areas emit more energy. If the radiating surface is opaque, the energy emitted by the surface and measured by the satellite is related to the temperature of the surface; otherwise, the radiation is a complicated function of cloud amount and structure". A preliminary estimate of overcast cloud top heights can be made by relating the Channel 2 equivalent blackbody temperatures to nearby radiosonde temperature-height data.

Channel 4, which covers the $8-12\mu$ window region as well as the $8-30\mu$ region, is characterized by strong absorption bands of carbon dioxide and water vapor.

Channel 1 responds to radiative contributions, depending upon the water vapor, temperature, and pressure profiles, from a broad region in the middle and upper troposphere.

The radiometer detects the radiation energy flux viewed during a scan by means of an optical system designed to chop the radiation and apply it to five thermistor detectors. A filter system separates the five spectral regions.

The radiometer's 5 degree view angle results in a field of view encompassing approximately 40×40 statute miles on the earth when the sensor's nadir angle is zero. An increase in the nadir angle elongates the field in the direction viewed. The optical axes of the five channels are all parallel and inclined to the satellite spin axis by 45 degrees. Three earth-scanning modes or patterns of the radiometer (Figure 3) may be described[3] as follows:

> *Closed Mode:* All scan spots throughout a number of spin cycles of the satellite are earth-viewed, either through the "wall" (side) sensor or the "floor" (baseplate) sensor.
>
> *Single Open Mode:* Some scan spots of a spin cycle are space-viewed and the remainder are earth-viewed through the wall sensor only or through the floor sensor only.
>
> *Alternating Open Mode:* The scan spots of a spin cycle are a combination of space- and earth-viewed, alternately through the wall sensor and the floor sensor.

The satellite's 8-12 rpm rotation provides the radiometer with a scan sweep that alternately views outer space (near zero radiation) and the earth's surface. The sensors measure the difference in energy flux over the scanned field of view. The sensor's output is recorded and transmitted to the ground stations where it is converted electronically into usable form. A detailed description of the data handling and conversion process has been published elsewhere.[4]

The output of the radiometers[5] can be described in terms either of equivalent blackbody temperatures (°K) or of radiant emittance (w/m^2) within the spectral response curve of each channel (Figure 4). The relative accuracies of Channels 1 and 2 were estimated to be $\pm 2\,^{\circ}C$ while the absolute values may vary by $\pm 5\,^{\circ}C$ as a result of second-order effects in the calibration procedure.[6]

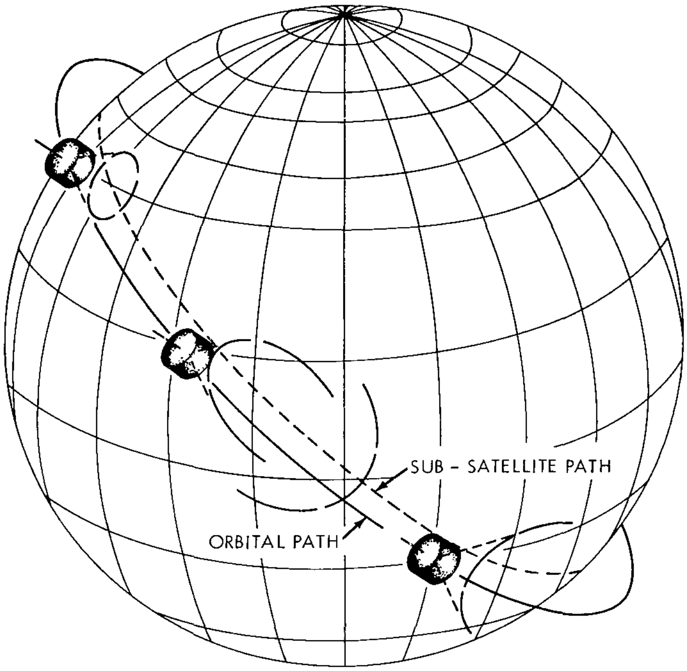

Figure 3—The scan patterns of the Tiros II 5-Channel medium resolution scanning radiometer. (The closed, single-open, and alternating-open modes are illustrated from left to right.)

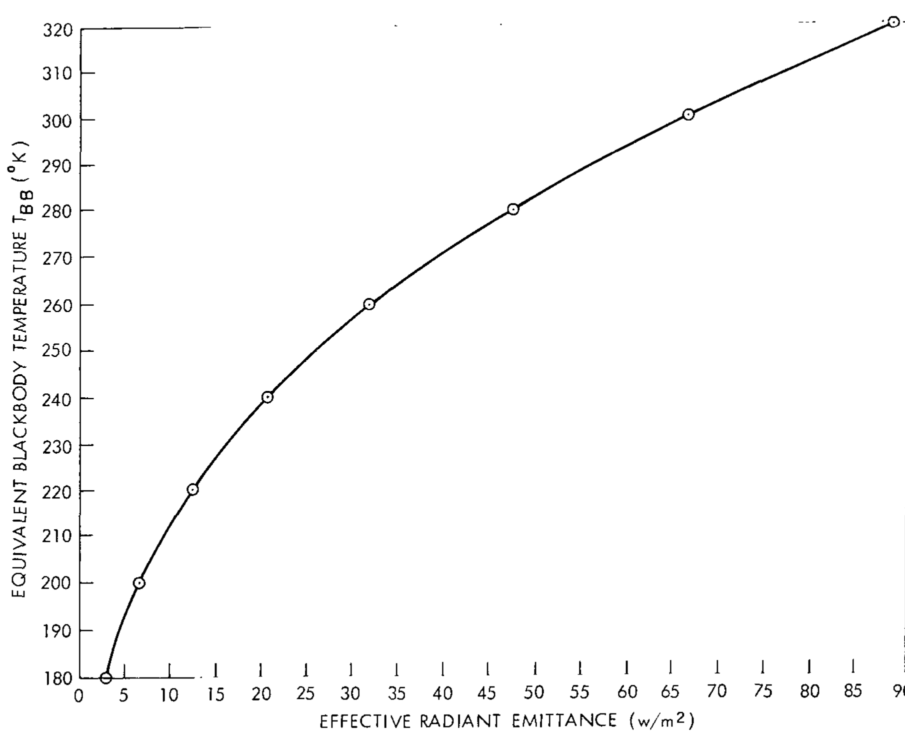

Figure 4—Equivalent blackbody temperature versus effective radiant emittance for Channel 2 of the Tiros II scanning radiometer.

The radiation data for Channels 2, 4 and 1 were recorded during a 7 minute period at approximately local midnight and were reduced to usable form[5] with the aid of an IBM 7090 computer. The satellite was spinning at 8.0 rpm at swath 1 (1223 GMT), 700 miles southeast of Australia. The camera nadir angle was 127 degrees at swath 1 and slowly changed to 159 degrees at swath 74 (1232 GMT). The swath (radiation viewing path) changed from a parabolic arc to a nearly circular sweep pattern during this period.

ANALYSIS OF THE TIROS II RADIATION DATA

Four independently analyzed surface charts for 1200 GMT, November 23, 1960, were requested and received from the New Zealand and Australian Meteorological Services, the Commander of the U. S. Naval Support Force in Antarctica, and the International Antarctic Analysis Center at Melbourne, Australia, by courtesy of the U. S. Weather Bureau representative. A final composite synoptic chart and nephanalysis (Figures 5 and 6) were made from the above charts with the assistance of Lt. Comdr. John D. Ploetz, Wintering Over Officer 1960, U. S. Naval Weather Service, Washington, D. C.

The two cold-type surface meridional occlusions shown in Figures 5 and 6 had moved east and southeast off the east coast of Australia, and had intensified in the Tasman Sea, within the preceding 24 hours (November 22-23, 1960). A long north-south band of low equivalent blackbody temperatures (cold radiation sources) in the Tasman Sea (Figures 7, 8 and 9) 240° to 258°K, 233° to 255°K, and 225° and 237°K, for channels 2, 4, and 1 respectively—clearly outline these well-developed occluded fronts. The shading indicates areas of cooler equivalent blackbody temperatures. By relating the above mentioned Channel 2 temperatures to nearby radiosonde data, it was estimated that the dense high overcast cloud layers in the meridional occlusions extended to heights of 5-7 kilometers.

Fritz and Winston[2] estimated the heights of the cloud tops over the United States during Orbit 4 (daytime) by use of upper air constant pressure charts, radiosonde reports, and the conversion to height of Channel 2 equivalent blackbody temperatures. It was noted that the Channel 2 blackbody temperatures recorded over thin cirriform clouds over surface fronts related to the infrared emission of the less opaque cirriform clouds and the denser (warmer) altiform and/or stratiform cloud layers below. Thus, the presence of thin high cloud layers can only be deduced by an intelligent analysis of the radiation data, synoptic situation and from climatological data.

Smaller cold radiation areas over the rugged mountain ranges of New Zealand indicate orographic-type clouds while larger cold radiation sources at 173°E longitude and 50°S latitude probably indicate alto- or cirriform-type clouds on the west side of a maritime 1022-mb surface high. Broad areas of warm equivalent blackbody temperatures 265° to 282°K, 261° to 273°K, and 237° to 246°K for channels 2, 4 and 1 — occur over two surface high pressure regions. Warm radiation sources indicate areas that are: (1) cloudless, or (2) covered by warm low clouds, or (3) covered by scattered or broken clouds over a warm surface.[2] The first and third weather condition best describes the synoptic cloud cover over the weak surface maritime highs.

An air temperature and air-sea temperature difference chart for 1200 GMT, November 23, 1960 was drawn and analyzed. The waters within 10° to 15° latitude of Christchurch showed a negligible

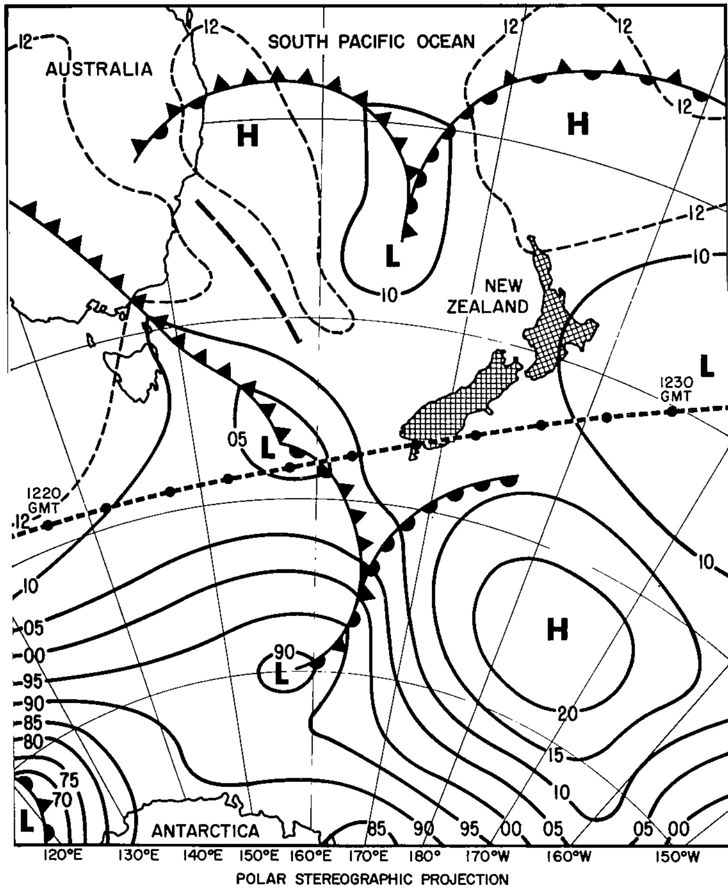

Figure 5—Surface synoptic chart for the New Zealand area, showing sea-level isobars and fronts at, 1200 GMT, November 23, 1960. The satellite track during Orbit O is shown by a heavy dashed line, with a dot indicating every minute of time.

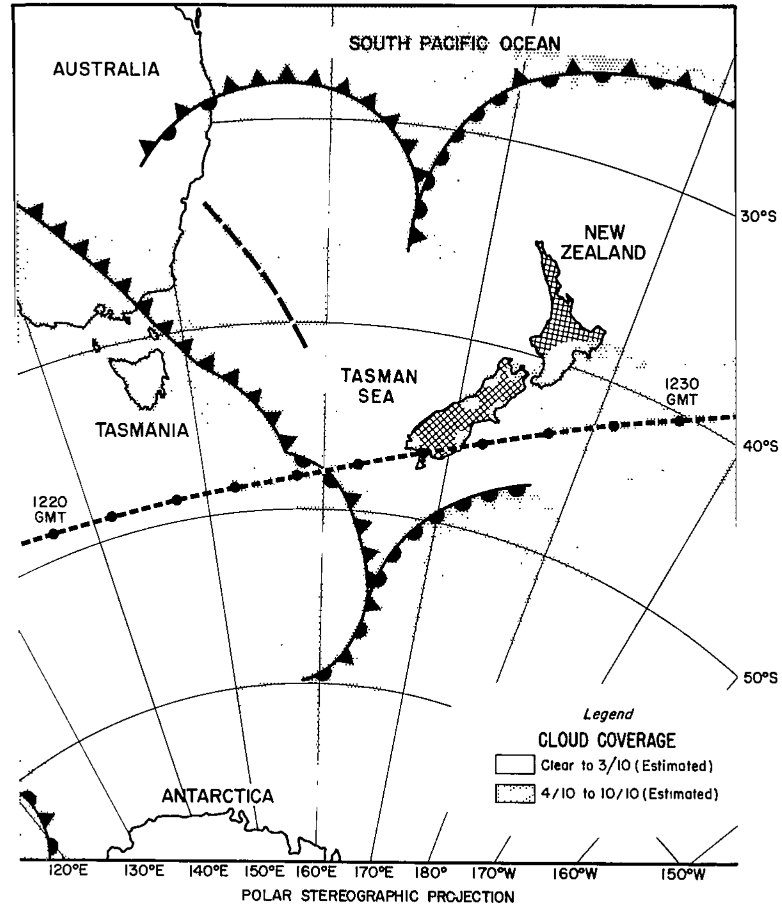

Figure 6—Nephanalysis of the surface synoptic chart for 1200 GMT, November 23, 1960, on Orbit O of Tiros II.

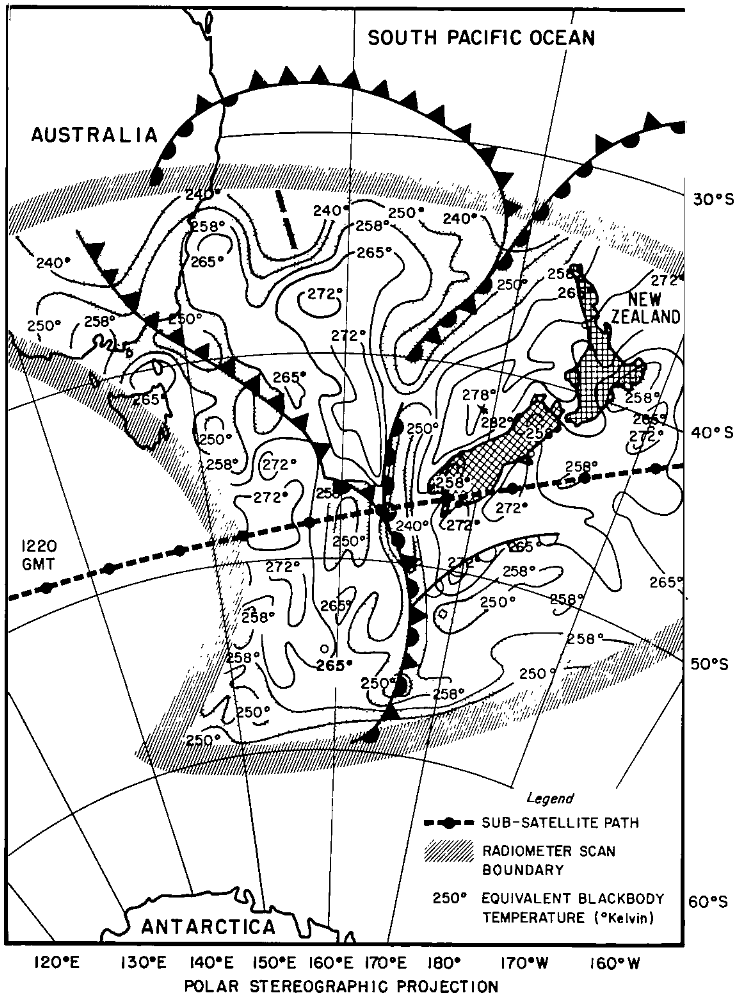

Figure 7—Radiation maps from the Tiros II 5-channel scanning radiometer: Channel 2, Orbit O, 1220-1230 GMT, November 23, 1960. Equivalent blackbody temperatures of 258°K or less are shaded.

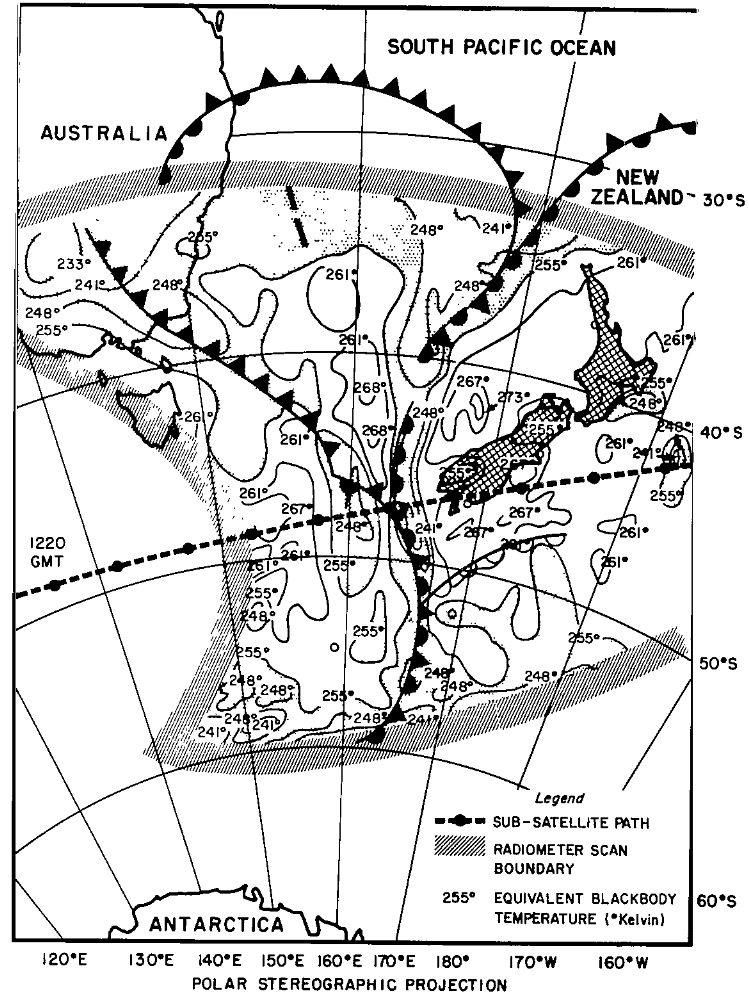

Figure 8—Radiation maps from the Tiros II 5-channel scanning radiometer: Channel 4, Orbit O, 1220-1230 GMT, November 23, 1960. Equivalent blackbody temperatures of 255°K or less are shaded.

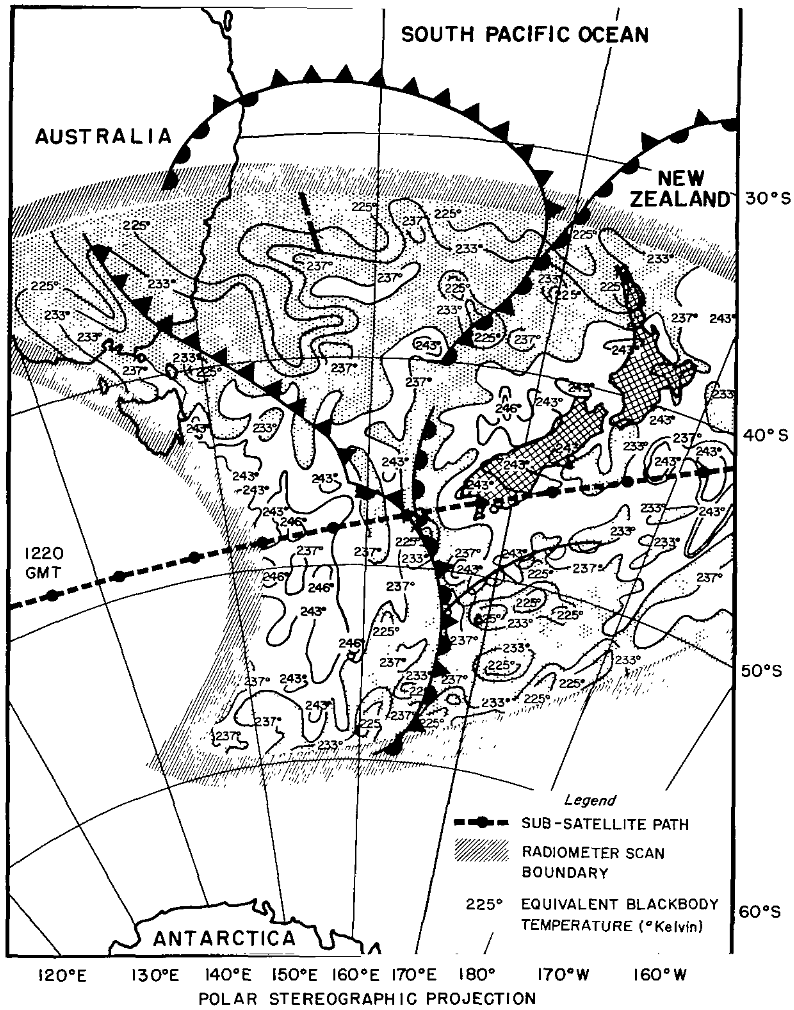

Figure 9—Radiation map from the Tiros II 5-channel scanning radiometer: Channel 1, Orbit O, 1220-1230 GMT, November 23, 1960. Equivalent blackbody temperature of 237°K or less are shaded.

(± 1°—2°K) air-sea temperature difference both for the 1200 GMT synoptic period and for a Marsden Square oceanographic summary for November[7] (Figures 10 and 11). On air temperature and air-sea temperature comparison was made where the warmest Channel 2 equivalent temperatures (282° and 278°K) had occurred. At 168°E, 42°S, the Channel 2 equivalent temperatures were noted to be 6° to 12°K colder than the sea water temperatures (Figure 10). This temperature difference was probably caused by the presence of low clouds and/or by the fact that some energy is still received in Channel 2 from atmospheric water vapor and ozone; i.e., this channel is not an entirely transparent "window."[8]

Aircraft weather reports[9] plotted from 0013 GMT, November 23, 1960 (Figure 12) helped to verify the 1200 GMT surface synoptic analysis (Figure 5). Multiple layers of low clouds (stratiform and cumuliform, with bases at 3000-5000 and tops at 6000-8000 feet), middle clouds (altostratus-altocumulus, with bases at 8000-11,000 and tops at 18,000 feet), and high clouds (cirrostratus with bases at 25,000 feet), and lines of thunderstorms (cumulonimbus—0351 GMT) were reported in the

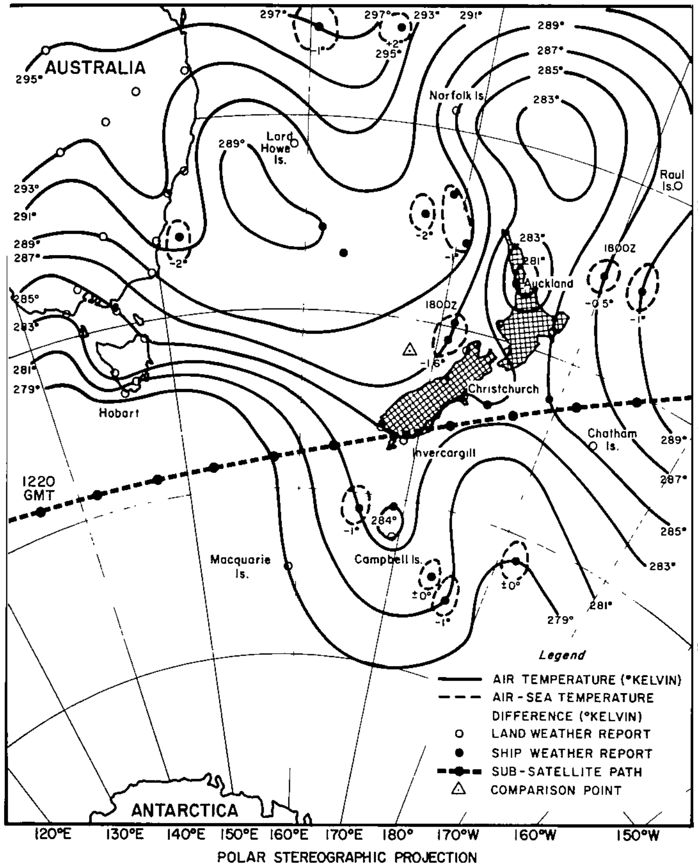

Figure 10—Surface air temperature and air-sea temperature difference chart for the New Zealand area at, 1200 GMT, November 23, 1960.

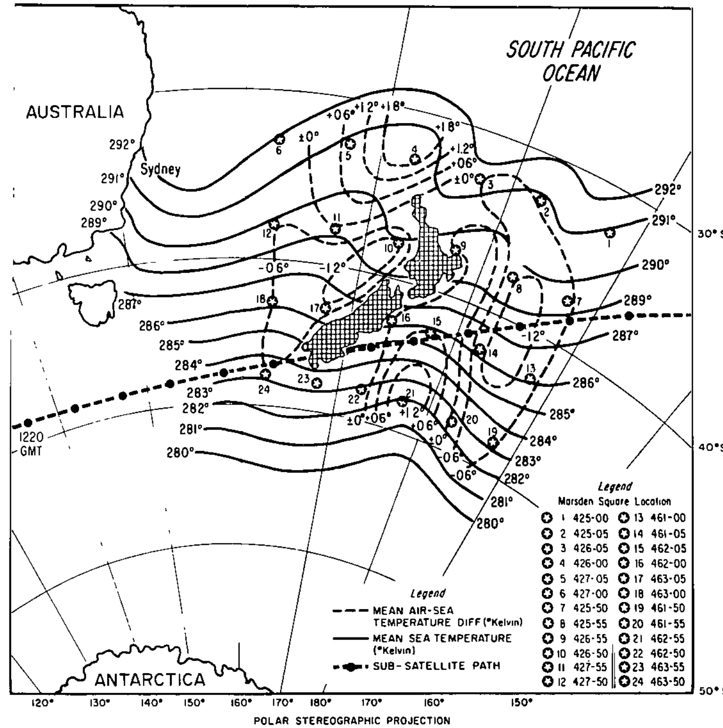

Figure 11—Mean air-sea temperature difference and sea temperature chart for November (1900-1956) for the New Zealand area.

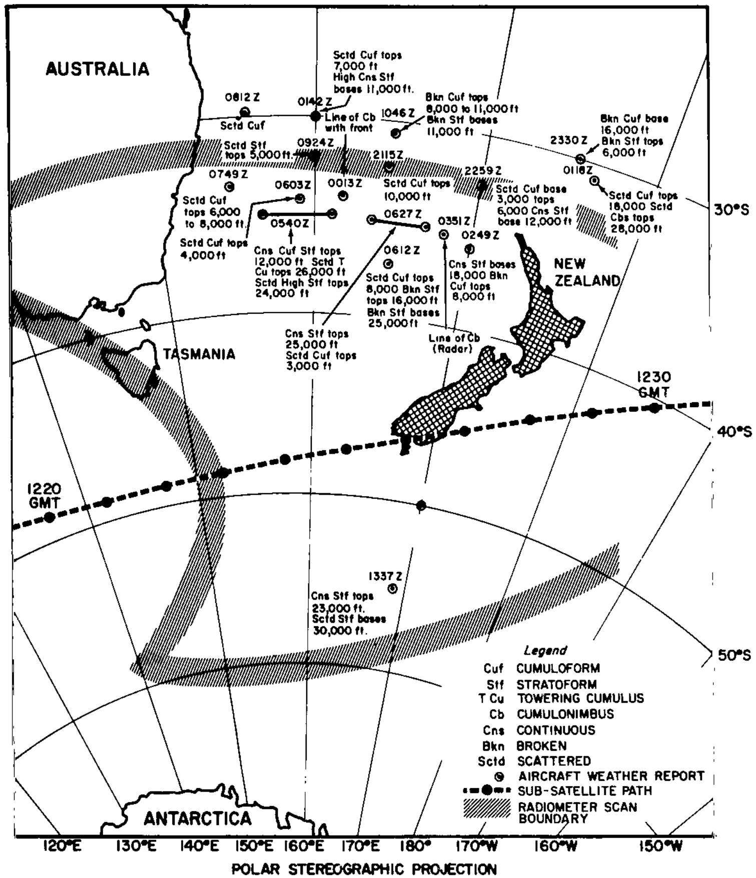

Figure 12—Aircraft weather reports for the New Zealand area, 0013-2330 GMT, November 23, 1960.

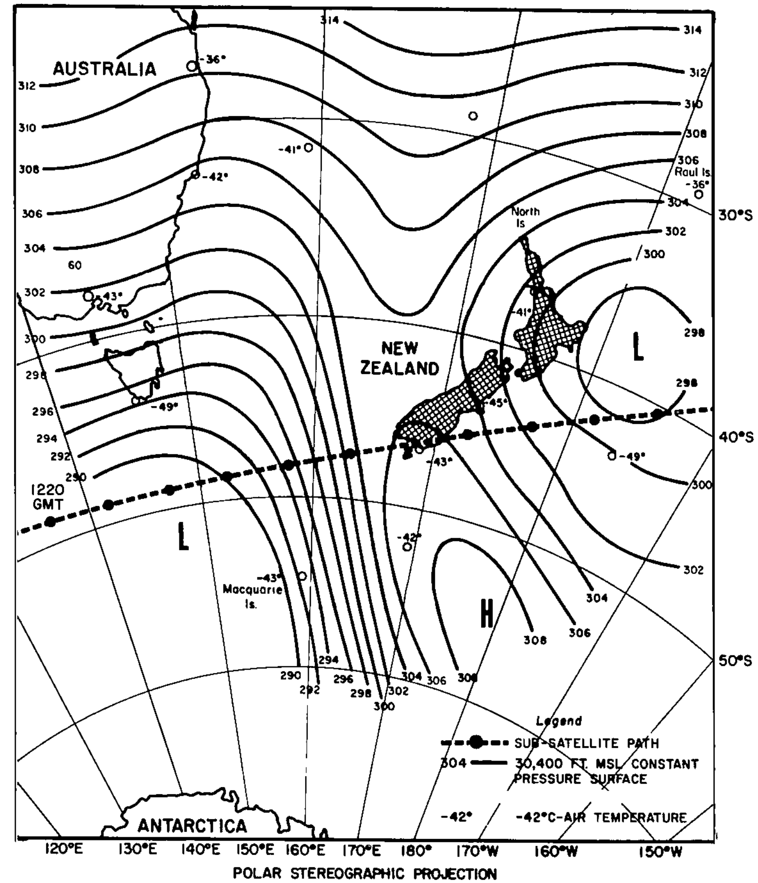

Figure 13—300 mb constant pressure chart for the New Zealand area at, 0000 GMT, November 23, 1960. Tiros II, Orbit O.

area of the meridional occlusion between 160° and 170°E and 30° and 40°S. Broken altostratus and cirrostratus cloud layers were reported by aircraft at 0612 and 0627 GMT in the same area. The presence of these dense, opaque cloud decks with tops at 18,000-25,000 feet is confirmed by the 240°-258°K equivalent blackbody temperatures recorded 6 hours later by Channel 2 (Figure 7) in the Tasman Sea.

Pilot weather reports, aided by aircraft radar, were considered to be among the most valuable sources of cloud information at night over this remote maritime area.

The most detailed upper air information for the 850 mb up through the 200 mb constant pressure level was available at 0000 GMT, November 23 and 24, 1960. The 300 mb chart (Figure 13) for 0000 GMT, November 23 was selected to show the strong circulation pattern which persisted from the 700 mb to the 200 mb level for the 24 hour period. A strong jet stream (140 knots maximum) was oriented SSE/NNW over Macquarie Island, approximately 5 degrees west of the surface front. An 80 knot isotach maximum was located over the northeast tip of North Island, New Zealand. The 300 mb chart was included in order to complete the upper air analysis for the area.

On the basis of the subjective interpretation of the three well correlated sets of radiation data (Channels 2, 4, and 1) and all synoptic charts, the warm front originally drawn south of New Zealand was redrawn as an upper warm front and the surface portion was placed meridionally to the west of South Island, New Zealand (Figures 7, 8, and 9).

Thus, the meteorologist, through the judicial combination of Tiros II radiation data, aircraft weather reports, and all available surface charts and upper air information, can obtain a reasonably detailed nocturnal description of the horizontal and vertical cloud distribution in the stormy Tasman Sea.

TROPOPAUSE HEIGHT ESTIMATION

Widger and Touart[10] and House and Blankenship[11] have indicated that the Channel 1, 6.0-6.5μ radiation data may be useful in estimating tropopause heights. Hanel and Wark[6] have shown that Channel 1 responds to water vapor emission in a broad region of the middle and upper troposphere, the maximum contributions emanating from the vicinity of 400 mb.

In order to verify this height estimate, the tropopause heights for the New Zealand area were determined in accordance with World Meteorological Organization definitions[12] from Figure 14 and drawn in Figure 15. Channel 1 equivalent blackbody temperatures over 5 radiosonde stations were converted to "effective radiation heights" by means of Figure 14. The effective "heights" were subtracted from the actual tropopause sounding heights at 0000Z on November 23, 1960 and averaged (Table 1). The base of a lower inversion at 36,350 feet at Invercargill was used in Table 1, because it closely approximated the WMO definition for a conventional tropopause. The lower polar tropopause height (32,700 ft) was used at Auckland, which exhibited a multiple tropopause structure.

Table 1 indicates that the Channel 1 (6.0-6.5μ) maximum integrated radiation level averaged 8705 feet below the tropopause; this qualitatively confirms the work of Hanel and Wark. The T_{BB} for Channel 1 averaged 18°K warmer than the tropopause temperatures, in this study.

W. R. Bandeen, (Private communication, September 1962) suggested an empirical equation to obtain a closer tropopause height estimate from the Tiros Channel 1 data:

$$\text{Tropopause Height} = 55{,}000 - 530 \left(T_{BB} \text{ Chan. } 1\text{-}200\right) . \qquad (1)$$

A comparison of the tropopause height from the same radiosonde soundings with the tropopause heights estimated by use of Equation 1 is shown in Table 2. The difference between the radiosonde and estimated tropopause heights ranged from +1010 to -2690 feet at radiosonde stations with single and multiple tropopauses.

Defant and Taba,[13] in their worldwide hemispheric investigation of tropopause heights and temperatures, stated: "With the exception of the very northern latitudes (75° to 90°N), the close relationship between tropopause height and tropopause temperature seem to be almost perfectly fulfilled in the sense that an increase in height goes parallel with a decrease in temperature or vice versa (compensation principle)." One can presume that the same relationship holds for the southern hemisphere.

Since tropopause temperatures and heights are operational requirements for the stratosphere flights of military and civilian aircraft,[14] more comprehensive studies of these parameters with Tiros radiation data will be made in the future.

Table 1

Comparison of Heights and Temperatures at the Tropopause as Determined from Radiosonde and Tiros Channel 1 Data.

Station	Radiosonde Tropopause Data (Figure 13)			Channel 1 "Effective" Height			Height Diff. (ft)	Temp. Diff. (°K)
	Height (ft)	Pressure (mb)	T_{BB} (°K)	Height (ft)	Pressure (mb)	T_{BB} (°K)		
Auckland	32,700	266	228	27,280	340	237	5,420	9
Invercargill	36,350	230	218	26,930	358	240	9,420	22
Campbell Is.	39,200	200	211	30,980	295	230	8,220	19
Macquarie Is.	34,800	230	219	22,350	405	242	12,450	23
Christchurch	33,850	257	221	25,840	365	238	8,010	17
							AVG: 8,705	18

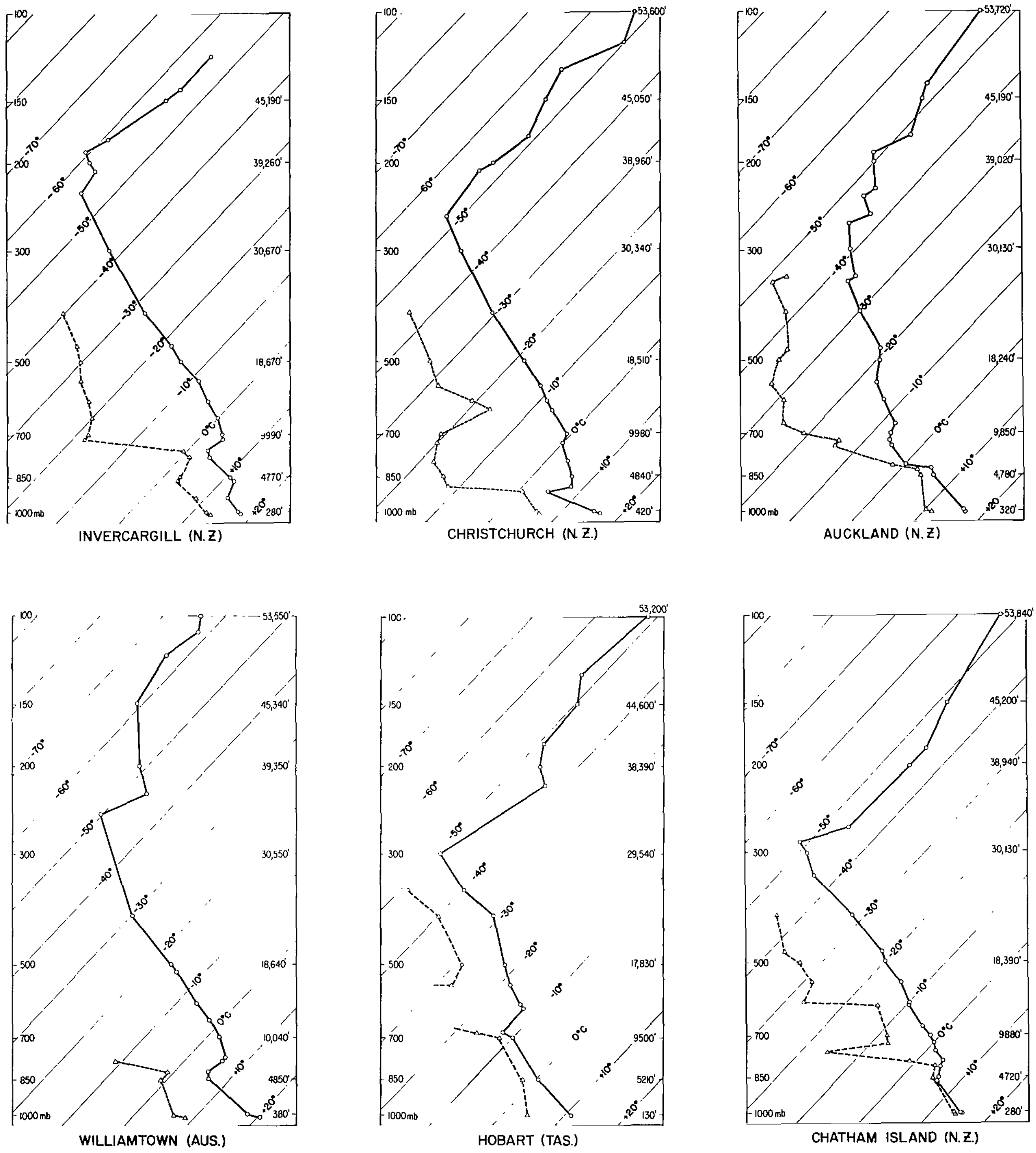

Figure 14—Radiosonde Soundings, at 0000 GMT, 23 November 1960. The solid line shows temperature distribution; the dashed line, dewpoint distribution.

CONCLUSION

The results described in this study point to the important meteorological potential of satellite infrared radiation data in synoptic observation of frontal and air mass movement, interpretation of large scale upper air flow patterns, and investigation of the atmospheric heat budget.[15,16,17]

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